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An Empirical Analysis on Regional Technical Efficiency of Chinese Steel Sector Based on Network DEA Method

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Abstract

This paper studies the regional technical efficiency of Chinese steel sector based on a network DEA model during the period of 2006-2010, which takes account of the real steel production process. Compared with the traditional DEA method, network DEA method has the advantages that it does not need model assumptions on input/output orientation and avoids the dilemma on the choice of input/output indicators. The comparison analysis shows that network DEA model produces more reasonable efficiency results than the traditional DEA model. The empirical results indicate a steady increase in technical efficiency of Chinese steel sector. In addition, the technical efficiency of Chinese industry sector in eastern area, central area and western area is unbalanced, with a lower efficiency in the west and a higher one in the east.

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Keywords: Technical efficiency; Steel sector; Network DEA

1. Introduction

Chinese steel sector has played an important role in the development of Chinese industry since the late 1970s, and now become the pillar industry of national economy in China. However, the serious excess capacity phenomenon in the steel sector has emerged especially across the periods of Tenth and Eleventh Five-Year plans. The capacity utilization of China's steel is between 70%-75%, which is less than the international average level. China is accelerating the process of industrialization and urbanization, and the steel sector still plays a fundamental role in the economy development and city construction, both at present and in the foreseeable future. Therefore, reasonable measurement of technical efficiency of Chinese steel sector can help

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us analyze regional differences in steel sector, and explore the reasonable product structure and regional distribution characteristics. A comprehensive comparison analysis of regional technical efficiency of Chinese steel sector is important, not only to the elimination of backward production capacity, but also to the policy making on mergers and reorganizations of steel enterprise in different regions. Moreover, we can propose some recommendations for governments when making many policies about steel industry development, which is beneficial to maintain social stability during digesting the excess capacity and realize sustained and healthy development.

There is a large number of researches on productivity and efficiency performance of Chinese steel sector. In this study, we will focus on the technical efficiency of Chinese steel sector. Technical efficiency measures the maximum possible expansion of the outputs for a given level of the inputs and technology, i.e. the ability of a production unit to produce as much outputs as the inputs allow, and this is helpful for a deeper understanding with regard to the rationality of input-output structure. But the existing studies mainly focused on the productive and technical efficiency of steel enterprises as well as regional or sectional energy efficiency, and paid little attention to discriminating regional technical efficiency of Chinese steel sector (e.g. Wu [1,2], Zhang and Zhang [3], Ma et al. [4], Movshuk [5], Kim et al. [6], Wei et al. [7], Zhang and Wang [8], Lin et al. [9], He et al. [10], Sheng and Song [11]). Wu [1,2] analyzed technical efficiency and its relationship with some firm attributes such as ownership, scale and location by applying a production frontier model which can estimate firm-specific, time-varying efficiency. Zhang and Zhang [3] identified the sources of diverse performance of China's iron and steel enterprises. Ma et al. [4] employed Malmquist Productivity Index (MPI) to study the productivity change of Chinese steel sector. Movshuk [5] evaluated the impact of major reform initiatives on enterprise performance in China's iron and steel industry based on a stochastic frontier model with panel data. Kim et al. [6] examined the technical efficiency of firms in the steel sector to try to identify the factors contributing to the industry's efficiency growth. Wei et al. [7] investigated that China's iron and steel industry energy efficiency increased, which was mainly attributable to technical progress. Zhang and Wang [8] found that the increase of technique updating and transformation investments associated with energy conservation enhanced the productive efficiency of Chinese iron and steel enterprises. Lin et al. [9] evaluated the energy saving potential of the Chinese steel industry by studying its potential future energy efficiency gap. He et al. [10] took undesirable outputs into consideration by using the Malmquist–Luenberger Productivity Index (MLPI) to explore the productivity change of Chinese steel sector from 2006 to 2008. Sheng and Song [11] used the firm-level census data to re-estimate the total factor productivity (TFP) of firms in Chinese steel industry and examined its potential determinants over the period 1998-2007.

For the measurement of technical efficiency, DEA is a nonparametric approach developed by Charnes et al. [12] as a technique to assess the performance of a set of different decision-making units (DMUs) based on the work of Farrell [13], and now has became a widely used methodology for evaluating relative efficiency. DEA measures the relative efficiency under the situations in which there are multiple inputs and outputs, and identifies the relative efficient DMUs based on the best performance and evaluates the efficiency of other DMUs relative to a linear combination of the efficient DMUs. However, its basic production process considers each DMU consumes specific levels of selected inputs to produce DMU-specific levels of selected outputs, but makes no assumptions regarding the manner in which a DMU converts inputs into outputs. That is, DEA method deals with the internal production process as a "black box" when measuring the efficiency and ignores the information on the production process. In order to overcome this problem, various approaches to network DEA have been proposed (Färe and Grosskopf [14], Castelli et al. [15], Sexton and Lewis [16], Lewis and Sexton [17], Hold and Lewis [18]), the advantages of which are the greater insight in the DMU production process. In this study, we will use an alternative efficiency evaluation method in the network DEA framework, which is more in accordance with the underlying production process.

The objective of this paper is to estimate technical efficiency of steel sector in Chinese different provinces and analyze the regional differences. Our paper contributes to the literature on Chinese steel sector by employing a network DEA efficiency measurement method, which can give more reasonable efficiency measurement for further study on exploring variation characteristics and influencing factors of efficiency. The remainder of this paper is organized as follows. Section 2 describes the methodology used in this paper. Section 3 gives data statistics and relevant area division. Section 4 offers the comparison analysis between traditional DEA method and network DEA method when dealing with intermediate products and empirical results of regional efficiency evaluation for Chinese steel sector. Section 5 summarizes our conclusions and attempts to draw some policy implications.

2. Methodology

Now we consider a production system with n DMUs, and each DMU has three factors: input indicators, intermediate product indicators and output indicators, as represented by three vectors: $x \in R^m$, $z \in R^p$, $y \in R^l$. We define the matrices X, Z, Y as following:

$$X = [x_1, x_2, \cdots, x_n] \in R^{m \times n},\ Z = [z_1, z_2, \cdots, z_n] \in R^{p \times n},\ Y = [y_1, y_2, \cdots, y_n] \in R^{l \times n}.$$

In traditional DEA methodology framework, the production process of each DMU is treated as a black box, so we only consider the input indicators and output indicators. The intermediate products are usually considered as inputs or outputs by different researchers. In addition, we have to decide the input-oriented or output-oriented before using the DEA method for efficiency evaluation, and the corresponding models can be formulated as follows:

[Input-oriented DEA]

$$\begin{aligned} \rho^* &= \min \theta_0 \\ \text{s.t.}\quad & \theta_0 x_0 \ge X\lambda \\ & y_0 \le Y\lambda \\ & \sum_{j=1}^{n} \lambda_j = 1, \lambda \ge 0, 0 \le \theta_0 \le 1 \end{aligned} \tag{1}$$

[Output-oriented DEA]

$$\begin{aligned} \rho^* &= \min \theta_0 \\ \text{s.t.}\quad & x_0 \ge X\lambda \\ & \theta_0 y_0 \le Y\lambda \\ & \sum_{j=1}^{n} \lambda_j = 1, \lambda \ge 0, 0 \le \theta_0 \le 1 \end{aligned} \quad . \tag{2}$$

However, in the network DEA framework, the production process can be divided into two or more sub-DMUs' production processes, and part of the inputs (or outputs) for one sub-DMU are produced (or consumed) by other sub-DMUs. In this study, we will utilize the unoriented network DEA method proposed by Hold and Lewis [18], which may have the potential to produce more consistent efficiency measurement. For simplicity, we consider a two-stage network DEA model as shown in Fig. 1 and the production possibility set (P) is defined by

$$P = \{(x, z, y) \mid x \ge X\lambda, z = Z\lambda, y \le Y\lambda, \lambda \ge 0\}. \tag{3}$$

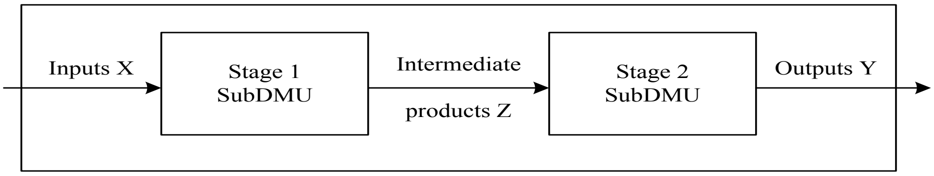

Fig. 1. The schematic diagram of the production process in two-stage network DEA model.

For evaluating DMU$_0$ (x_0, z_0, y_0), the two-stage network DEA model can be formulated as follows:

[Unoriented two-stage network DEA] $\rho^* = \min \theta_0$

Subject to

$$\begin{aligned} &\theta_0 x_0 = X\lambda + S^x \\ &z_0 = Z\lambda \\ &\varepsilon_0 y_0 = Y\lambda - S^y \\ &S^x \geq 0, S^y \geq 0, \lambda \geq 0, \sum_{j=1}^{n} \lambda_j = 1 \\ &\varepsilon_0 + \theta_0 = 2, 0 \leq \theta_0 \leq 1, \varepsilon_0 \geq 1 \end{aligned} \quad , \qquad (4)$$

where $S = (S^x, S^y)$ corresponds to the slack variables in inputs and outputs, and the target function value of ρ^* is the relative efficiency.

3. Data and summary statistics

3.1. Selection of production indicators

This paper employs the panel data of the Mainland China's 26 provinces, autonomous regions or municipalities from 2006 to 2010. The provinces of Hainan, Ningxia, Qinghai and Tibet are not included because of the statistic information missing, and we add the data of Chongqing to that of Sichuan province. The sample period focuses on the "Eleventh Five-Year" plan.

For the input indicators, we choose investment in fixed assets in steel industry as a good proxy indicator for capital, and use the number of employed persons involved in steel industry activities at the end of each year as the labor force indicator. In this paper, we consider a two-stage production process for simplicity. Based on the network DEA model for efficiency measurement in steel industry, we choose pig iron as the intermediate product, and the crude steel and finished steel are selected as final outputs. The data comes from China Statistical Yearbook and China Iron and Steel Industry Yearbook, published by the National Bureau of Statistics of China. The basic statistics of input, intermediate and output indicators are shown in Table 1.

Furthermore, as shown in Table 2, there is a significantly positive correlation between output and input indicators at the significance level of 1%, which meets the ''isotonic'' condition in the DEA methodology framework (Lang and Golden [19]).

Table 1. Descriptive statistics of input, intermediate and output indicators

	Input indicators		Intermediate indicator	Output indicators	
Variables	Capital C	Labor L	Pig iron P	Crude steel CS	Finished steel FS
	Billion-yuan	Ten-thousand people	Million-tons	Million-tons	Million-tons
Mean	11.666	7.308	19.468	20.250	24.140
Median	8.108	5.718	12.125	12.428	16.452
Maximum	61.843	22.388	148.177	144.588	171.135
Minimum	0.138	1.750	2.338	3.047	2.785
Std.Dev	12.032	5.378	24.207	24.187	27.396
Skewness	2.142	1.530	3.157	3.124	2.882
Kurtosis	8.142	4.371	14.552	14.132	12.890

Table 2. Pearson correlation coefficients between production indicators

Index	C	L	P	CS	FS
C	1.0000	0.7705***	0.8291***	0.8308***	0.7877***
L		1.0000	0.7512***	0.7280***	0.6658***
P			1.0000	0.9898***	0.9460***
CS				1.0000	0.9735***
FS					1.0000

Note：“*”、“**”、“***” represent their significance levels of 10%, 5% and 1% respectively.

3.2. Area division of the Mainland China

As we all know, China has the unbalanced economic growth and industrial development priorities for steel sector. According to the traditional division method, we divide China into eastern area, central area and western area as shown in Table 3.

Table 3. Three areas division of the Mainland China

	The provinces in the corresponding area
Eastern area	Liaoning, Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong
Central area	Jilin, Heilongjiang, Shanxi, Anhui, Jiangxi, Henan, Hubei, Hunan
Western area	Inner Mongolia, Guangxi, Guizhou, Yunnan, Shaanxi, Gansu, Xinjiang, Sichuan

These three areas have significant differences in many aspects such as geographic position, economic strength, resources, and the population density. For examples, the GDP contribution and economic development in eastern area are obviously higher than the other two areas. In addition, steel industry in eastern area has the advantages of ports transport and market demand. The central area is the base of agriculture and has a large population. The western area has the lowest population density and is least developed, but steel demand still has some improvement potential accompanying with further development of the western area.

4. Technical efficiency measurement for Chinese steel sector

4.1. The comparison of technical efficiency between traditional DEA and network DEA methods

Based on the traditional DEA and network DEA methods mentioned above, we can measure the technical efficiency of Chinese steel sector. Here, we first aim finding the differences in technical efficiency measured by traditional DEA treating the intermediate products as either input or output. We apply DEA model under different orientation assumptions and compare the efficiency results produced by the alternative models that use intermediate products (pig iron) as either input indicators or output indicators. We use In-DEA (Out-DEA) to denote the technical efficiency of Chinese steel sector produced from the traditional DEA models by treating pig iron as an input (output), and use Network DEA to denote the technical efficiency produced from the network DEA model treating pig iron as an intermediate product. All tests in Table 4 are corresponding to the efficiency score series of traditional In-DEA and Out-DEA models.

Table 4. Comparison analysis of technical efficiency by traditional In-DEA and Out-DEA models

Input-oriented: Test for equality of means			Output-oriented: Test for equality of means		
Test Method	Value	Probability	Test Method	Value	Probability
t-test	5.1523	0.0000	t-test	7.8753	0.0000
Welch F-test	26.5457	0.0000	Welch F-test	62.0206	0.0000
Input-oriented: Test for equality of medians			Output-oriented: Test for equality of medians		
Test Method	Value	Probability	Test Method	Value	Probability
Wilcoxon/Mann-Whitney	4.3882	0.0000	Wilcoxon/Mann-Whitney	6.2851	0.0000
Med.Chi-square	7.4462	0.0064	Med.Chi-square	23.4014	0.0000
Input-oriented: Test for equality of variances			Output-oriented: Test for equality of variances		
Test Method	Value	Probability	Test Method	Value	Probability
F-test	2.1520	0.0000	F-test	2.9066	0.0000
Siegel-Tukey	4.0157	0.0001	Siegel-Tukey	5.7178	0.0000

Under the input-oriented or output-oriented assumptions, Table 4 shows that the efficiency scores produced from traditional In-DEA and Out-DEA models are significantly different with respect to the efficiency mean, efficiency median and efficiency variance, and this comparison results are robust for different test methods. That is to say, when using traditional DEA model to measure technical efficiency of Chinese steel sector, the choice of whether to treat pig iron as an input or an output appears to affect the efficiency scores significantly. The dynamics of technical efficiency of steel sector may be affected by the researcher's choice of whether to treat pig iron as an input or an output. Actually, during the steel production process, pig iron is just an intermediate product. If we treat pig iron as output as in Out-DEA model, more production of pig iron is better, but the low value deviates from the high value-added aim of steel production. If we treat pig iron as input as in In-DEA model, less production of pig iron is better which cannot guarantee input demand in the next stage of steel production.

Therefore, we will consider a unifying framework by the network DEA method that captures the steel production process more appropriately in order to avoid this dilemma. This network DEA model considers minimizing inputs and maximizing outputs under the premise of pig iron production unchanged. Furthermore, the efficiency scores may affect the efficiency-based ranking of the individual steel sector in different provinces, so we compute the correlations of the efficiency scores for each pair of models (In-DEA, Out-DEA, Network DEA), see Table 5.

Table 5. Correlations of the technical efficiency scores between different models

	Input-oriented			Output-oriented		
Pearson correlations	In-DEA	Out-DEA	Network DEA	In-DEA	Out-DEA	Network DEA
In-DEA	1.0000	0.7198	0.9434	1.0000	0.6660	0.8970
Out-DEA	-	1.0000	0.8379	-	1.0000	0.8118
Network DEA	-	-	1.0000	-	-	1.0000
Spearman rank correlations	In-DEA	Out-DEA	Network DEA	In-DEA	Out-DEA	Network DEA
In-DEA	1.0000	0.7323	0.9477	1.0000	0.6619	0.9065
Out-DEA	-	1.0000	0.8507	-	1.0000	0.8199
Network DEA	-	-	1.0000	-	-	1.0000

From Table 5 we can find that all correlations (Pearson correlations and Spearman rank correlations) are positive. However, the correlations between efficiency scores produced from In-DEA and those produced from Out-DEA are below 0.75, which indicates that the two models produce divergent ranks. The correlations between efficiency scores produced from In-DEA or Out-DEA and those produced from Network DEA are above 0.8. Moreover, the correlations between In-DEA and Network DEA are higher than those between Out-DEA and Network DEA, which is similar with the findings of Hold and Lewis [18] when studying the bank efficiency. Therefore, when we are not sure whether some intermediate product is input or output, then treating intermediate product as input indicator may be a better choice.

To summarize, we demonstrate that the network DEA efficiency model produces reasonable results for Chinese steel sector. Therefore, the choice of whether to treat pig iron as an input or an output matters for the estimated average efficiency as well as for the ranking. In the following section, all the analysis on regional technical efficiency of Chinese steel sector are based on the efficiency scores produced from network DEA model.

4.2. Technical efficiency of steel sector in Chinese different provinces and tendency analysis

Table 6 presents the summary results for technical efficiency of Chinese steel sector, and some interesting observations emerge. Firstly, there is a steady rise of technical efficiency from 2006 to 2010. This is because during the “Eleventh Five-Year” plan, China's steel sector vigorously develops and produces domestic relative shortage of steel products, and the productivity and quality of high-end special steel production continuously improve. In addition, some steel enterprises such as Baogang and Angang have an obvious enhancement of independent innovation capability. Secondly, the province of Inner Mongolia has the lowest technical efficiency and the efficiency scores present inverted U-shaped curve from 2006-2010. Although the steel industry in Inner Mongolia has a period of rapid development from 2002 to 2010, there are many deficiencies. For example, in Inner Mongolia there are many small mills, which tend to produce low cost and relatively poor quality products. This leads to mass production of low value-added products and low technical efficiency. In particular, this phenomenon is more serious during the sub-prime financial crisis. Thirdly, the technical efficiency of most provinces such as Beijing, Hebei, Shanxi, Liaoning, Fujian and Gansu has an obvious fall in the years of 2007 and 2008, when the sub-prime financial crisis has happened. Due to the financial crisis, steel consumption expectation have decreased significantly, which affects the exports of steel production, especially to the European Union countries and regions, North America. Therefore, the production of high value-added products also decreased. Fourthly, the technical efficiency of some provinces such as Beijing, Fujian, Guizhou and Hubei has large fluctuations.

Table 6. Technical efficiency of steel sector in different provinces from 2006 to 2010

	2006	2007	2008	2009	2010	Mean	Std.dev.
Beijing	0.8435	0.6800	0.9432	0.9879	1.0000	0.8909	0.1330
Tianjin	0.7676	0.8112	0.8733	0.9551	0.9971	0.8809	0.0959
Hebei	0.9880	0.9660	0.9473	1.0000	1.0000	0.9803	0.0231
Shanxi	0.6854	0.7460	0.6513	0.8173	0.8957	0.7591	0.0991
Inner Mongolia	0.3754	0.4962	0.6187	0.5606	0.5345	0.5171	0.0909
Liaoning	0.7083	0.7666	0.7190	0.7251	0.7906	0.7419	0.0351
Jilin	0.8053	0.7958	0.7553	0.8320	0.7465	0.7870	0.0356
Heilongjiang	1.0000	0.9451	1.0000	1.0000	0.9613	0.9813	0.0263
Shanghai	0.7770	0.7845	0.7779	0.8489	0.9511	0.8279	0.0752
Jiangsu	0.9616	1.0000	1.0000	1.0000	1.0000	0.9923	0.0172
Zhejiang	1.0000	1.0000	1.0000	0.9404	1.0000	0.9881	0.0267
Anhui	0.6622	0.7095	0.7548	0.7930	0.7102	0.7259	0.0498
Jiangxi	0.9920	0.9916	0.9961	1.0000	1.0000	0.9959	0.0041
Fujian	1.0000	0.8381	0.6967	0.8925	0.8804	0.8615	0.1098
Shandong	0.8309	1.0000	1.0000	0.9170	1.0000	0.9496	0.0755
Henan	0.7618	0.8162	0.9232	0.7258	0.7743	0.8003	0.0759
Hubei	0.6516	0.6762	0.7384	0.8397	0.9753	0.7762	0.1329
Hunan	0.7007	0.7094	0.6915	0.6362	0.6518	0.6779	0.0321
Guangdong	0.8760	1.0000	0.9684	0.9334	1.0000	0.9556	0.0523
Guangxi	0.8114	0.8635	0.7427	0.6762	0.7582	0.7704	0.0710
Sichuan	0.6555	0.7225	0.6966	0.5946	0.6451	0.6629	0.0493
Guizhou	0.7951	0.8708	0.8440	0.6396	0.6048	0.7509	0.1212
Yunnan	0.7473	0.8197	0.7244	0.7853	0.7145	0.7582	0.0438
Shaanxi	1.0000	1.0000	1.0000	0.9823	0.8739	0.9712	0.0550
Gansu	0.7136	0.7612	0.7196	0.7928	0.7640	0.7502	0.0332
Xinjiang	1.0000	1.0000	0.9620	1.0000	1.0000	0.9924	0.0170
Average value	0.8119	0.8373	0.8363	0.8414	0.8550	-	-

4.3. Technical efficiency of steel sector in three areas and tendency analysis

According to the area division of China, the three areas' technical efficiency scores of steel sector from 2006 to 2010 and their development tendency have been given in Table 7. The average technical efficiency scores of the eastern, central and western areas across years in Table 7 are 0.9069, 0.8130 and 0.7717 respectively. It means that efficiency scores of central and western areas would have about 11.5% and 17.5% enhancement potential under the present amount of inputs and outputs, if they want to reach the eastern area's technical efficiency level. Furthermore, technical efficiency of steel sector in three areas increases from west to east, which suggests the regional unbalanced development of Chinese steel sector. The growth rate of technical efficiency in central and western areas is lower than that in eastern area. The eastern area has much superiority such as coastal location, level of economic development and market demand, which can be helpful to reduce transportation costs of raw materials, the introduction of advanced technology and innovation. The steel industry in central and western areas has a rapid development, but the product structure and layout still relatively backward and regional advantages cannot fully be exploited.

Table 7. Technical efficiency of steel sector in three areas from 2006 to 2010

year	2006	2007	2008	2009	2010	Average
Eastern Area	0.8753	0.8846	0.8926	0.9200	0.9619	0.9069
Central Area	0.7824	0.7987	0.8138	0.8305	0.8394	0.8130
Western Area	0.7623	0.8167	0.7885	0.7539	0.7369	0.7717
Overall Area	0.8067	0.8333	0.8316	0.8348	0.8461	0.8305

Note: The value of Overall Area is the average efficiency score of Eastern Aera, Central Aera and Western Aera.

5. Conclusions and policy implications

This paper assesses the performance of regional technical efficiency of Chinese steel sector by a network DEA method, and this efficiency model has the superiority over traditional DEA method which does not consider the steel production process. We have given a comparative analysis on efficiency differences between traditional DEA method and network DEA method, and demonstrated the advantages of network DEA method when dealing with steel production process with intermediate products. The empirical results provide some evidence on the development tendency and characteristics of regional technical efficiency of Chinese steel sector. We observe that provincial technical efficiency of steel sector has significant differences. Three areas' technical efficiency has unbalanced development and increase from west to east. Technical efficiency of steel sector has a steady improvement during the Eleventh Five-Year plan. Although Chinese steel sector has a rapid development, there are still great regional differences in technical efficiency of steel sector. Therefore, we should further optimize the steel industrial layout according to inland and coastal characteristics, market demand and regional economic development. The eastern area should further develop high value-added steel products. The central area should actively promote structural adjustment and industrial upgrading to deepen technological innovation. Western area should give key considerations to the factors such as energy, iron ore, environment and market.

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